

HARNESSING THE POWER OF TECHNOLOGY



THE ROAD TO BALLISTIC MISSILE DEFENSE FROM 1983-2007

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TABLE OF CONTENTS

Summary	1
Introduction	5
Ballistic Missile Defense Basics	5
Approaching the BMD Challenge	12
BMD Missions, Eras, and Dynamics	16
The Beginnings of SDI – Exploration of Technologies (1984-1987)	17
Developing a Strategic Defense System – The Phase 1 Architecture (1987-1991) .	21
Transition – Global Protection Against Limited Strikes (GPALS) (1991-1993)	24
The Primacy of Theater Missile Defense (1993-1996)	27
The Re-emergence of National Missile Defense (1996-Present)	32
The Road Ahead (2000-2007)	37
Conclusion	40

Appendix

 The Road to Ballistic Missile Defense: 1983-2007

HARNESSING THE POWER OF TECHNOLOGY

The Road to Ballistic Missile Defense from 1983-2007

SUMMARY

Introduction. After decades of technical breakthroughs and billions of research and development dollars, the Department of Defense is on the threshold of acquiring and deploying ballistic missile defense systems to protect the United States, its allies, and deployed military forces. Nine interceptor tests since March 1999 have resulted in successful destruction of ballistic missile targets.¹ Concept feasibility has now been demonstrated across all three tiers of the evolving layered defense architecture, inside and outside the atmosphere (endo- and exoatmospheric) for theater missile defense, and for the more demanding requirements of a national missile defense.

Over the past 50 years, the US scientific community, industry, and the military Services have explored, prototyped, and tested generations of missile defense related technologies, components, and system concepts. Beginning with President Reagan's Strategic Defense Initiative in 1983, the Strategic Defense Initiative Organization (SDIO) and its successor, the Ballistic Missile Defense Organization (BMDO), have led these efforts. This paper summarizes the technological advances these agencies have demonstrated in their roles as responsive agents and responsible stewards of the Defense resources entrusted to them.

Threat. The ballistic missile threat emerged during World War II with the bombardment of England by V-2s. The Cold War married ballistic missile technology with nuclear weapons and brought the missile threat directly to the United States, as the Soviet Union created a massive arsenal of nuclear tipped ICBMs and, later, SLBMs.² The ballistic missile threat changed significantly during the 1990s. By 1991, the collapse of the Soviet Union made a major nuclear attack on the United States less likely, but a missile threat continued nonetheless. The Gulf War, with its televised images of Scud-vs-Patriot battles, awakened Americans to the global proliferation of ballistic missile technology. It

Changing Threat Drivers

The Primary Threat Against Which Ballistic Missile Defenses Have Been Designed

The Cold War Threat

- Massive attack from the USSR
- Coming from one primary direction
- Focused on US territory
- Carrying nuclear warheads

The Post-Cold War Threat

- Limited attack from hostile 3rd World nations
- Coming from several possible directions
- Possible on US, overseas forces, or allies
- Potentially carrying weapons of mass destruction including nuclear warheads

¹ TMD: PAC-3 had four successful intercepts and no failures; THAAD had two successful intercepts after six earlier consecutive failures, and the Israeli Arrow had two successes and no failures.

NMD: Exoatmospheric Kill Vehicle (EKV) had one successful intercept on 2 Oct 1999 and two failures.

² Intercontinental Ballistic Missiles and Submarine Launched Ballistic Missiles

also brought the realization that ballistic missiles had ushered in a new dimension of warfare. Not only were they a direct threat to US forces and interests overseas, they also gave their owners significant potential psychological and political leverage. With a few Scud missiles, Saddam Hussein was able to threaten the integrity of the allied coalition and to preoccupy thousands of allied ground, sea, and air troops, even to this day.

Over the past decade, the flow of Soviet, Chinese, and North Korean ballistic missile technology to and among Third World nations has increased. In July 1998, the Rumsfeld Commission highlighted the imminent and growing threat of increasingly capable ballistic missiles from some nations to American interests, allies, and deployed forces, and potentially even to the United States itself. As if to validate the report, in August that same year, the North Koreans demonstrated a ballistic missile capable of hitting Alaska and parts of Hawaii with weapons of mass destruction. And they did it 11 years earlier than nominal US intelligence community predictions.

Response. The dynamics of this changing missile threat have affected how the United States approached securing its interests. Cold War tensions had spurred the development of defenses by both the United States and Soviet Union. The latter developed, deployed, and has maintained around its capital city, Moscow, a ballistic missile defense system using interceptors with nuclear warheads. The United States briefly deployed a defensive system (Safeguard), also based on a nuclear tipped interceptor, in North Dakota in the mid-1970s to protect the adjacent offensive strategic missile fields. In 1976, however, that system was shut down for reasons of cost and operational effectiveness, and the US lost all capability to protect its retaliatory forces or population from an incoming ballistic missile attack. Today, the United States still has none.

Since then, America has depended on its offensive strategic missile capability to deter ballistic missile attacks on its homeland, a policy of mutual assured destruction. It also sought important security objectives through negotiation. The early 1970s saw the Strategic Arms Limitation Talks, or SALT I framework, for limiting strategic offensive arms and constraining strategic defenses. The latter effort, embodied in the US-USSR Anti-Ballistic Missile (ABM) Treaty – modified in 1974 and subsequent continuing discussions – set basic design, test, and deployment boundaries for American BMD¹ programs. Among other provisions, the treaty framework banned any defense of all of a nation's territory, and limited signatories to one ABM site with no more than 100 ground-based interceptors. The development, testing, or deployment of sea, air, space, or mobile ABM systems was also prohibited.

By the early 1980s, Soviet advances in missile weaponry threatened the survival of the fixed, quick reaction elements of the US retaliatory force on which mutual assured destruction rested. The Soviets had increased missile accuracy sufficiently to make their

¹ **Ballistic Missile Defense** includes **National Missile Defense** (NMD), to protect the United States homeland, and **Theater Missile Defense** (TMD), to protect deployed forces, allies, and friends elsewhere in a theater of military operations. As used in this paper, the term missile defense does not include defense against cruise missiles that can be directed against both the United States and targets in theaters overseas.

ICBMs “silo-busters” and had developed multiple warheads to overwhelm earlier defense designs. New mobile missiles could evade an initial attack. These changes in the threat, some promising new technologies, and the moral failings of a strategy which rested on either surrender or mass suicide, prompted President Reagan’s 1983 challenge to the scientific community to find ways to make nuclear weapons “impotent and obsolete.”

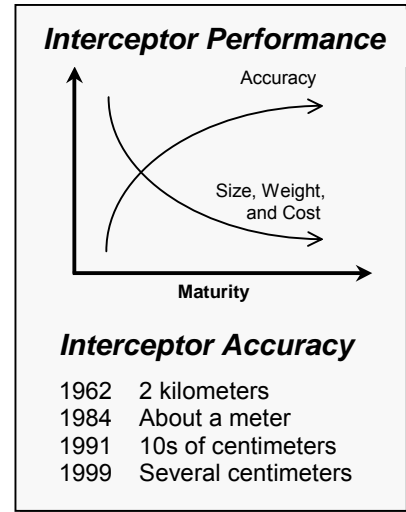
Evolution of Missions. Between 1985, the first budget year after President Reagan’s launched his initiative, and 1999, the Congress has authorized and appropriated, and the Department has allocated, approximately \$50 billion (a little over one percent of the DoD budget during this period) for research, development, and ultimate deployment of a viable missile defense capability. The period can be divided into five eras, during which the American missile program was driven by changes in the perceived threat and by separate and distinct missions given the program by successive Administrations and the Congress.

- 1984-1987: Explore technologies for national ballistic missile defense
- 1987-1991: Start acquisition of a phased national ballistic missile defense
- 1991-1993: Acquire a limited global missile defense capability
- 1993-1996: Develop and field a theater missile defense capability, while continuing national missile defense as a technology readiness program
- 1996-1999: Continue to acquire theater defenses, and develop a national missile defense system for possible limited deployment.

Each of these periods saw changes in the geostrategic setting, revisions in how best to provide for US security, evolution in ways to harness maturing technologies in integrated defense architectures, advances in technologies themselves, and development of the systems and procedures to comprise an effective defense. As program emphasis shifted during this 16-year period, the SDIO and BMDO adjusted to develop technologies of merit that are now on the verge of providing increased safety for Americans and the security of their interests at home or abroad.

Technology Efforts. Efforts focused on the three major elements of any ballistic missile defense: sensors, weapons, and controls. Sensors were developed for the extreme ranges and environments in which they had to operate (through the atmosphere or in space). A large data base was collected so that these sensors could reliably interpret and report what they saw. Non-nuclear weapons systems designs were pursued to destroy missiles or their warheads, effectively and ideally at adequate distance from the intended point of impact. As research progressed, it appeared that directed energy designs did not have the range or power to destroy inherently rugged reentry vehicles at reasonable cost. At the same time, Hit-to-kill designs (destruction of the attacking missile by homing in on and colliding with it, rather than by explosion) evolved as the concept of choice because they could deliver far more energy directly on the target for the mass involved. Systems for control, or battle management, faced some of the greatest challenges in tying together information from many sources, in real time, knowing which weapons would best be used to engage any target at any point in its trajectory, and allowing the right decisions to be made in very short periods of time – with humans directing those decisions.

Technology Results. As technologies were identified and developed and as components were integrated into systems, they started to meet some fundamental parameters. Operational performance and reliability were paramount, since the consequences of failure would be catastrophic. Reductions in size and weight of key system components and hardware were realized, as these tended to decrease reaction times, increase range, and reduce overall life cycle costs. The biggest advances were in: miniaturized, enhanced processing power; streamlined communications throughput; sensor sensitivity and response; and radar detection and discrimination. As these enhanced technologies began to be integrated into components and systems, overall performance increased geometrically. New technologies were exploited or developed to facilitate manufacturing production for deployment at lowest cost.



The BMD technology advances to date have been dramatic. The 1984 Homing Overlay Experiment interceptor weighed approximately 1,200 kg; the 1991 Exoatmospheric Reentry Vehicle Interceptor Subsystem (ERIS) interceptor weighed 160 kg; and the current kill vehicle designed for the national missile defense system weighs only 55 kg. Among the payoffs have been agility and accuracy. In 1962, a Nike Zeus missile came within two kilometers of its dummy ICBM target, judged close enough for a kill with a nuclear weapon. In 1984, the Homing Overlay Experiment, with its unfurled arms, destroyed its target by impact. By 1991, ERIS had improved on that accuracy, and the current generation of interceptors can achieve an even more direct collision on the target center of mass.

The Prospect. Four theater missile defense systems are baselined for deployment by Fiscal Year 2007 and, depending on the plans of the Administration and Congress, a national missile defense system could become operational by Fiscal Year 2007 as well. For the first time, an effective, globally deployable theater and a limited national missile defense capability could exist to protect against a wide spectrum of the ballistic missile threats that could be used for coercive blackmail or to attack the United States or its allies.

BMD Systems Scheduled for Possible Deployment by 2007*

- Patriot PAC-3
- Navy Area
- Theater High Altitude Area Defense
- Airborne Laser
- National Missile Defense

*Contingent on Administration and Congressional approval

INTRODUCTION

After decades of technical breakthroughs and billions of research and development dollars, the Department of Defense stands on the threshold of acquiring and deploying a series of layered ballistic missile defense systems to protect the United States, its allies, and deployed military forces.

Over the past 50 years, the US scientific community, industry, and the military Services have explored, prototyped, and tested new generations of missile defense related technologies, components, and system concepts. Since President Reagan's Strategic Defense Initiative started in 1983, the Strategic Defense Initiative Organization (SDIO) and its successor, the Ballistic Missile Defense Organization (BMDO), have led these efforts. This paper summarizes the technological advances demonstrated by these agencies in their roles as responsive agents and responsible stewards of the Defense resources entrusted to them.

Because some readers may be unfamiliar with some of the terminology and concepts of ballistic missile defense, a basic primer on the subject is provided below, followed by a section on how SDIO and BMDO approached the ballistic missile defense challenge. Five broad historical eras can be identified for the program over the past 16 years, and each is described in terms of the geostrategic setting, architectural and technological developments, budget emphasis, and major accomplishments. The result is an emerging capability to enhance US interests and national security.

An appended foldout chart illustrates some of this history and the evolution of major BMD systems.

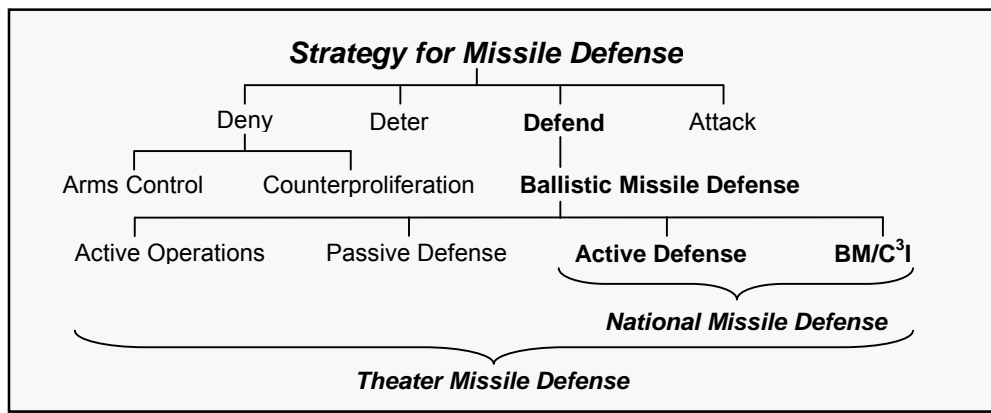
BALLISTIC MISSILE DEFENSE BASICS

Strategy for Missile Defense. Ballistic missile defense (BMD) is an important, but not the only, part of America's strategy for countering the ballistic missile threat, as can be seen from the diagram below. BMD itself has four components:

- Attack operations – offensive forces to destroy launch facilities, surveillance means, or command and control elements before a ballistic missile can be fired
- Passive defense – to minimize enemy ballistic missile effectiveness by actions such as deception, dispersion, or protective construction.
- Active defense – to destroy an enemy ballistic missile in flight
- Battle management/command, control, communications, and intelligence (BM/C³I) – the controlling and coordinating procedures and systems to provide effective defense.

Theater missile defense (TMD) involves all four of these, but attack operations and passive defense, are the responsibility of field commanders. National missile defense

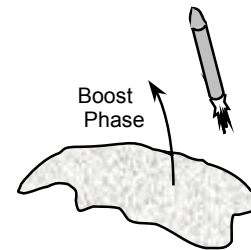
(NMD) involves just the last two. SDIO's and BMDO's development and acquisition responsibilities involve active defense and BM/C³I, for both TMD and NMD.



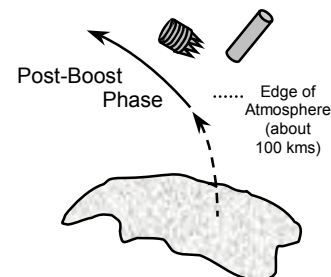
To understand the ballistic missile defense program and its evolutionary path, one must have a basic understanding of how ballistic missiles and missile defense systems operate.

Offense (the threat). A long-range ballistic missile's flight path between launch and terminal impact is normally described in terms of four phases. Each phase presents both opportunities and challenges for engagement by the defense.

- During the *boost phase*, the ballistic missile's rocket motor ignites and propels the missile into its desired trajectory. This is the most desirable yet most difficult phase in which to engage a missile. It is desirable because the missile's exhaust plume can be readily detected; although it is accelerating, it is traveling relatively slowly; there is one target, and intercept debris would likely fall well short of its intended target, though maybe not on enemy soil. On the other hand, difficulties for successful interception arise when the launch occurs deep in enemy territory. Similarly, boost engagement time is relatively short – on the order of one minute for a short range missile and perhaps four for an intercontinental one – during which time the missile must be detected, positively identified, engaged, and destroyed. At the end of this phase of powered flight, the missile is traveling fast – for an ICBM, perhaps as high as 15,000 miles per hour – making catching up with it a real challenge. This short window of opportunity stresses interceptor performance and human reaction time. Because much of this would likely take place in the atmosphere, weather can play a decisive role in obscuring some sensors.

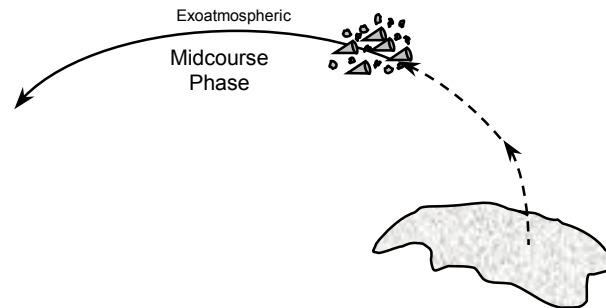


- The *post-boost phase* is that portion between the end of powered flight and the release of the last reentry vehicle (if threat missile employs one or more separating warheads). It is usually outside the atmosphere for a long-range missile, so that reentry vehicles (warheads) or submunitions and any penetration aids (such as chaff and decoys) can be released along ballistic trajectories to accompany the warhead(s).



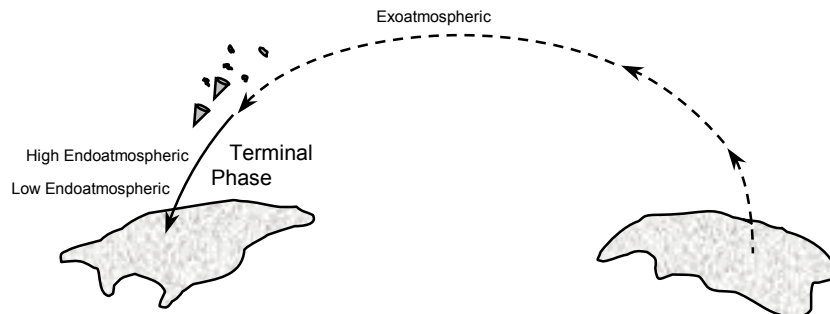
Hitting the warheads before deployment is desirable, but difficult because of the distance and time separation likely between targets and interceptors. Most intercept debris will continue along roughly the planned trajectory of the missile. Any debris that reaches the ground (is not burned up or dissipated in the atmosphere) would probably fall on friendly territory.

- In the *midcourse phase*, reentry vehicles, perhaps accompanied by penetration aids, coast outside the atmosphere (exoatmospheric) between last release and atmospheric reentry. Sometimes it is also defined as that phase after boost and before reentry – in other words, including the post-boost phase. Since it is usually the longest of the phases – perhaps as long as 20 minutes for an ICBM – there is more time for accurate trajectory predictions and engagement, maybe more than once. However, this period could also present the highest density of missile



countermeasures affecting warhead identification and tracking. Picking out the right target to hit (discrimination among warheads, penetration aids, spent boosters, miscellaneous parts) presents the most significant defensive challenge during this stage.

- In the *reentry or terminal phase*, the missile elements fall back into the atmosphere. This is a very short phase – on the order of 30 seconds or so – because of the speed of the traveling objects, now accelerated by gravity. Initially (high endoatmospheric), the reentry vehicles are still on relatively predictable trajectories, and the atmosphere begins to strip away some of the lighter debris. At lower levels (low endoatmospheric), filtering of all but the warheads has probably taken place, allowing for easier discrimination, but engagement here might not negate warhead effects, and any surviving debris may fall on friendly territory (as some did in the Gulf War).



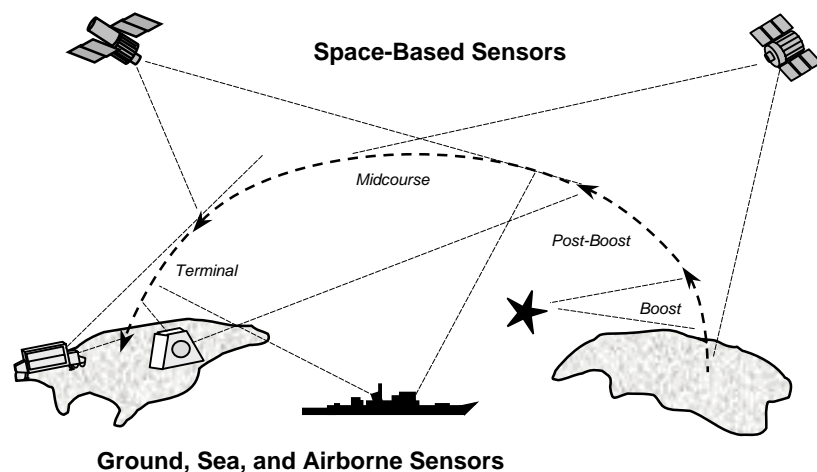
This illustrative example applies to long-range missiles, typically ICBMs. Short- and medium-range missiles may not travel as high (exoatmospheric), have separating warheads, or have sophisticated penetration aids. The Scud missiles used by Iraq in the Gulf War, for example, were designed to remain in one piece from launch to impact. Short-range missiles may have little or no midcourse phase.

Defense. The goal is to destroy the incoming missiles and make them ineffective; however, as in most military operations, this involves many separate functions. Ballistic missile defense involves surveillance, detection, identification, tracking, discriminating, intercepting, and assessing effectiveness (in the BMD case, whether the incoming warhead has been rendered ineffective). These functions require three generic types of system elements to operate: sensors, weapons, and controls.

- *Sensors and detectors* may be space-, ground-, or sea-based, or airborne. They may include passive sensors in the visible (optical), infrared, and ultraviolet ranges, and active sensors such as radars or ladars (laser detection and ranging). Sensors on satellites or interceptors are normally passive. Active sensors, because they require high levels of energy, are usually surface-based. Sensors can work individually or in networks. For example, initial missile/cluster detection may be provided by one set of sensors, perhaps from space, that cue or pass the necessary data to ground- or sea-based sensors for missile track and target identification. A terminal guidance sensor on the interceptor provides fine target tracking to home in exactly on the target.

Since one sensor cannot do it all, sensor design trades are made among target size, numbers of targets, search volume and frequency, tracking accuracy, and reporting timeliness to get the best performance at least cost. Emphasis on one performance parameter usually short changes another – a sensor that is good at detailed

discrimination, for example, cannot quickly search a wide area, and vice versa. Over the past 17 years, a rich variety of sensor concepts and designs have been pursued, yielding orders of magnitude advances in sensitivity, computational ability, compactness, and interconnectivity.

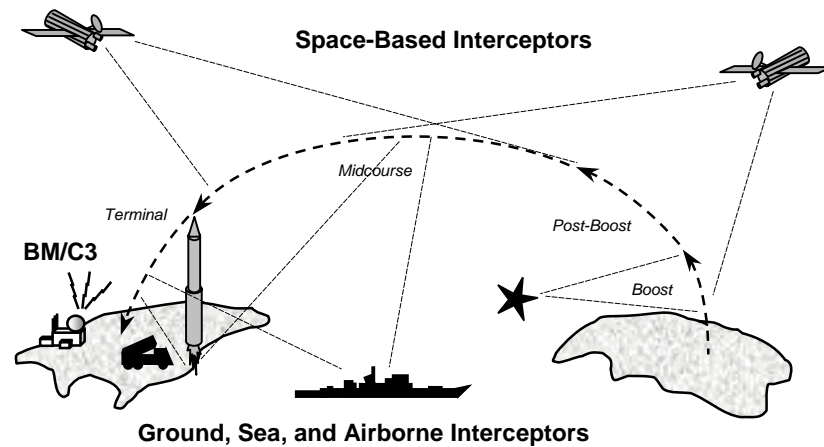


- *Weapons systems* may also be space-, ground-, or sea-based, or airborne.¹ A basic requirement is that a weapon system must deliver enough energy into the target to destroy or negate it. The more accurate the delivery, the less energy required. The current focus has been on nonnuclear hit-to-kill (HTK) interceptor systems that destroy by force of impact; nevertheless, directed energy (laser) research continues. Over the last 17 years, size and weight reductions have paid off for HTK interceptors, improving propulsion

¹ The ABM Treaty bars mobile ABM weapons development, testing, and deployment, but not research. Article V of the Treaty states “Each party undertakes not to develop, test, or deploy ABM systems or components which are sea-based, air-based, space-based, or mobile land-based.”

(speed and range), agility, accuracy, and lowering estimated costs of production by orders of magnitude.

- The *battle management/command, control, and communications (BM/C³)* systems integrate and coordinate the BMD architecture components. BM/C³ provides the planning,



coordination, direction, and control of the BMD systems as they execute their mission, whether the architecture consists of a single unit or tens of units. The key design trade-off is where to place the functions, with the central control element(s), sensors, or weapons. Advances over the past 17 years reflect orders of magnitude increases in computing power and improved ways for ensuring that people are involved in the key decisions without being overwhelmed by details.

Illustrative Engagement. As an example, assume that a Middle Eastern country launched multiple missile salvos at several targets on the Saudi Arabian peninsula. A space-based or an airborne sensor might first detect this action. If all missiles could not be successfully engaged in the early stages of flight, then cues (tracking and assessment information) could be passed to naval forces operating in the Gulf or Mediterranean, which would undertake to engage them in midcourse. Nevertheless, some missiles might get through. Ground forces closer to the target would then have to receive updated information in real time concerning the type, size, and characteristics of the remaining threat missiles, or “leakers,” to engage and destroy any of them. The entire engagement opportunity could be over in 7-10 minutes.

Even from this abbreviated scenario in a single theater, some conclusions can be drawn:

- A layered defense-in-depth is more effective than a simple perimeter defense. The consequences of allowing a single weapon of mass destruction to get through would be catastrophic. Two layers, for example, each with a theoretical 80 percent effectiveness, would provide a 96 percent confidence of successful defense; three such layers would provide over 99 percent confidence. Multiple layers operating in several different phases also complicate an attacker’s use of countermeasures. Decoys, for example, are of little value during boost phases.

Characteristics of Effective BMD

- Layered defense
- “Shoot-look-shoot”
- Multi-Service: (Air/Land/Sea/Space)
- Flexible architecture
- Integrated operations
- Human control

- A “shoot-look-shoot” capability able to gauge the success of a first intercept attempt, before firing off a second interceptor if warranted, can provide a more cost-effective defense than firing two or more interceptors at the same target at the same time.
- The forces of one military Service alone cannot guarantee an effective layered defense in all likely scenarios. Additionally, together and in concert, they may be able to defeat an enemy’s countermeasures that might be effective against any single layer.
- At the same time, the same numbers or types of defensive elements may not be available for each engagement. Flexibility must be built into overall system design (the architecture) to accommodate a varying mix of components. Naval forces may be the only ones available to provide defensive cover during the opening stages of an operation. Army forces may be the only ones within range for deep inland engagements.
- Because missile flight times are so short and windows of engagement so narrow, fully integrated, seamlessly interoperable, and multi-Service (joint) capabilities are essential.
- While computer-to-computer interfaces must be integrated and their interactions swift, human control remains an essential operational requirement.

Many of these considerations also apply to a national missile defense system.

The Anti-Ballistic Missile (ABM) Treaty. No informed discussion of the development of the BMD program can take place without an understanding of important aspects of the ABM Treaty, which the United States and the Soviet Union signed at the height of the Cold War to put mutual limits

on the strategic arms race by limiting ABM systems. Since the main concern then was for strategic missiles, the treaty imposes strict limitations on NMD, limiting the two nations to the testing (at agreed test ranges) and deployment (at one regional deployment site) of fixed, land-based ABM systems

Key Provisions of the ABM Treaty Framework

- Limited to one ABM site – no national defense
- No more than 100 ground-based interceptors
- No development, testing, or deployment of sea, air, space, or mobile systems
- No deployment of systems based on “other physical principles” (e.g., lasers, particle beams)
- Prohibits giving non-ABM systems (e.g., TMD) an ABM capability or testing them “in an ABM mode”

and components. The Soviets chose to defend Moscow. The United States initially chose to defend an ICBM site with the Safeguard system at Grand Forks, ND, but later abandoned even that venture. (Important to note is that President Reagan’s charge to SDIO was for research, with such activities being conducted below treaty thresholds.)

A mechanism for routinely updating the treaty framework was provided, and the treaty has been amended or supplemented a number of times since 1972, the most prominent being in 1974 when each country agreed to limit its deployment sites to one each, instead of the original two. Subsequent negotiations have included provisions defining thresholds for permissible theater missile defense as well. The 1997 Demarcation

Agreements (not yet ratified), in particular, establish certain permissible testing parameters for theater ballistic defenses, although the agreements are not intended to

1997 Demarcation Agreements for TMD*

- Establish speed and testing parameters for TMD systems
- Prohibit the development, testing, or deployment of space-based interceptors or components based on alternative technologies that could substitute for interceptor missiles

* Not yet ratified

resolve all TMD testing restrictions imposed by the ABM Treaty. These restrictions have become increasingly significant now that the line between the requirements for NMD and TMD has begun to blur with the increases in range and sophistication of the TMD threat. The well publicized North

Korean threat, for example, has emerged from a peninsular to a regional to a potentially intercontinental threat.

The BMD program has always remained compliant with the ABM Treaty. Good faith negotiations have been undertaken with the Russians regarding potential modifications to the treaty, required even with a limited NMD deployment.¹ If the President orders deployment of the NMD system and if the Russian Federation does not agree to such amendments, the United States, should it choose to do so, has the right to give six months notice and withdraw from the treaty.

¹ Mr. Walter Slocombe, Undersecretary of Defense for Policy, before the House Armed Services Committee, 13 October, 1999: "Our NMD development program has been and will continue to be carried out in compliance with the ABM Treaty. That compliance in the development phase has not slowed or curtailed the effort. It is clear, however, that deployment will require treaty modifications, and we have made clear to the Russians that we will seek to negotiate such modifications proceeding in good faith."

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APPROACHING THE BMD CHALLENGE

Investment in Strategic Systems. In many ways, the investment in and approach to the ballistic missile defense challenge has paralleled earlier American development of

Parallel Challenges for Strategic Systems

Offensive Requirements

- Early warning
- Booster propulsion
- Warhead
- Launch facilities
- Guidance
- Human control

Defensive Requirements

- Detection
- Kill vehicle propulsion
- Interceptor
- Launch platforms
- Guidance
- Human control

strategic offensive systems. Both were driven by perceptions of strategic need, both had major technical hurdles to overcome, and both pursued reduction in size and weight to reduce costs and increase efficiency. Advances in strategic offensive systems did not come easily. They were evolutionary in nature and had a significant price tag

(typically 5 to 10 percent of the DoD budget – many hundreds of billions of dollars) spread over more than four decades. Their system architectures had both national¹ and theater² elements that evolved through a number of system iterations.³ The BMD program, of course, had the advantage of being able to capitalize on all the earlier work already done.⁴ Missile defense now stands to have at least as much impact on our national security as has its more mature counterpart, and at a fraction of the cost.

Management Principles. Even as the threat and guidance have periodically changed, the BMD program has steered a consistent course through this variability by adopting a few key management principles.

- *Partnership.* The program has been open to participation by allies, and many have done so (especially NATO members and Israel). The result has been cost-effective sharing of data, facilities, and know-how. These efforts have strengthened political ties, reduced costs, and provided access to the best technologies. Additionally, the ability to integrate defensive operations with coalition partners during conflict or potential hostilities is essential for success. Interoperability with allies has been a continuing long-term goal. Discussions, for example, are ongoing with Japan on Pacific regional security issues and with Canada on North American ones, with our NATO allies and with Israel.

Principles for Management

- Partnership with allies and friends
- Affordability and cost-effectiveness
- Leveraging sunk costs and all sources
- Technology transfer to private sector
- Reuse of technologies as possible
- Open contracting with industry
- Extensive modeling and simulation

¹ Including ICBMs, SLBMs, and Long Range Bombers

² Including Ground Launched Cruise Missiles and the Pershing 2 IRBM

³ Including Atlas, Titan, Minuteman, and MX; Polaris, Poseidon, Trident C-4 and D-5; B-47, B-52, B-1, and B-2; BOMARC, Regulus, GLCM, and Pershing 1 and Pershing 2 respectively

⁴ For this reason, for example, the NMD program never pursued major booster technology because NMD components had access to many different mature commercial and government off-the-shelf systems.

- *Affordability.* No system was developed if it could not be shown to be cost-effective, although calculation of the costs of human life and property at risk in a missile engagement cannot be done.
- *Leveraging.* The challenges were so great that expertise was sought from as many sources as possible. The search was unconstrained in seeking all technologies relevant to BMD, including ones under development in the Services and elsewhere, such as technology on microprocessors and electro-optical systems. The net was cast nationwide for solutions, via the Small Business Innovative Research program and 8(a) support to minority concerns. Allied efforts were backed where possible. The Israeli ARROW program is the most visible and mature of these efforts.
- *Commercialization.* The other side of the leveraging coin is agency assistance in transferring SDIO/BMDO-developed technologies to the commercial marketplace for spin-off. Over 50 start-up companies have been formed to this end, and BMDO-funded technologies have led to over 600 patents and over 300 commercial products. Successful transfers have included sophisticated cancer detectors; higher quality, light weight communications equipment for cell phones; light satellite constellations; and more reliable automobile air bag systems.
- *Reuse.* Sunk costs were mined for technologies to minimize program costs. Technologies that fit the program were kept, and those that showed promise for the needs of the Services or others were passed to them for potential exploitation. Hit-to-kill (HTK) technology, for example, proved more mature than directed energy and was emphasized. Directed energy research continued, but at a more moderate pace. The initial potential of electromagnetic rail gun technology proved insufficient for the BMD program; however, the Army pursued it at a reduced level for possible tank/anti-tank application. BMDO research on infrared focal plane arrays has led to their expanded development and use throughout the defense community and industry.
- *Open Contracting.* Open competition procedures were instituted and subsequently became the Departmental norm. All potential industrial bidders had access to the same information through established document library holdings. Where appropriate, parallel developmental efforts were funded in phased competitive “horse races” to ensure that the program drew on the best industry could offer and at the lowest effective cost.
- *Modeling and Simulation.* While actual testing of hardware and software is absolutely necessary, it is also very expensive. The total cost of a single NMD interceptor flight test can be as high as \$100 million (up to \$50 million for a TMD test), which includes the cost of the target missile as well as the interceptor, operation of complex and often far-flung instrumented test ranges, prior validation of components. Because of this, BMDO has a major effort ongoing to analyze, evaluate, and anticipate alternatives and consequences. The program funded the initiation of a joint national test facility for computer simulations to make these assessments and provide sophisticated wargaming opportunities.

Technology Principles. Technology research was guided by mission requirements and the need to operate in the requisite environment. Thus, the conditions under which performance was expected had to be known, requiring in-depth phenomenology studies of how materials, sensors, and objects operated in space, the atmosphere, against countermeasures, and possibly in a nuclear effects environment.

As technologies were identified and developed, they had to meet certain key parameters. Performance and reliability were overwhelmingly important, since operational failure could be disastrous. At the same time, reductions in size and weight could lead to geometric increases in interceptor velocity, and hence range and area coverage. They were important as goals in their own right, because more capability was being designed into “smart” interceptors and space platforms, rather than just in ground handling equipment where size and weight were not such a concern. Furthermore, size and weight reductions often brought with them reduced costs, both for estimates of full scale production and for life-cycle operation.¹ Eventually, these technologies had to prove themselves reliable in the field, able to work outside a controlled laboratory environment.

Principles for Technology

- Support assigned missions
- Operate in the requisite environment
- Maximize performance and reliability
- Minimize size, weight, and cost
- Move toward “weaponization”

Advances in basic science and developments in pertinent technology have led to the maturity of the designs being incorporated in BMD today. Some promising technology concepts proved infeasible, others turned unaffordable, and still others operationally defective. In spite of such blind alleys typical of a pioneering effort, breakthroughs in subsystems such as navigation, propulsion, power generation, computers, signal processing, and optics have yielded significant results. Size and weight reductions and reliability improvements have enhanced performance and tended to lower projected life cycle system costs.

These are standard events in the acquisition of leading edge technologies and military systems. They also reflect a typically American strategy – the pursuit of, and leadership in, high technology warfare. The Department of Defense’s acquisition process is designed to support this strategy. It is an intricate system, with checks and balances to ensure that the nation’s resources are used wisely in meeting requirements. Even within this context, however, ballistic missile defense acquisition raises exceptionally demanding issues that make it, in many respects, an even more complex undertaking than strategic offensive or other traditional, high technology acquisition programs. That is because it must account for changing threat and countermeasures, real time requirements for heavy data processing, human control in compressed timeframes, hostile environments, and remote deployment on a potentially global scale, while still providing assured reliability.

¹ A direct payoff in weight reduction is reduced cost. A rule of thumb is that 10 lbs. of fuel are required to launch every pound of payload into orbit, and each pound put into orbit costs about \$10,000.

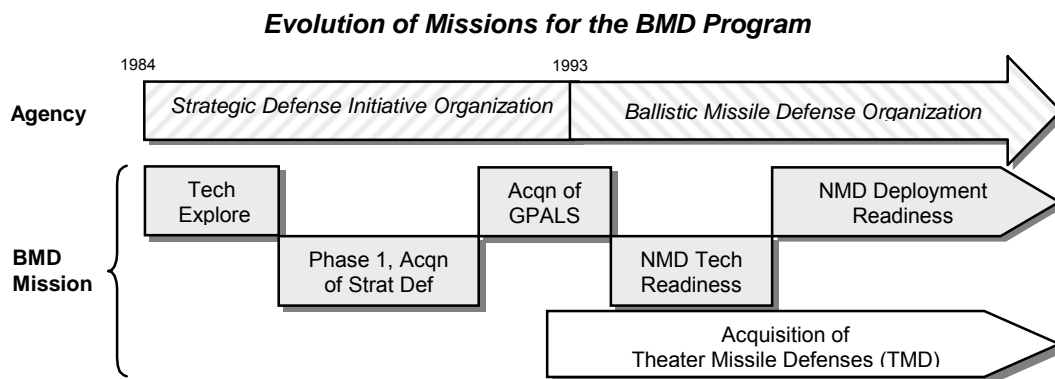
Added to these technological challenges is the fact that since 1983, the BMD program has been conducted in a more volatile programmatic environment than most other major acquisition programs. Changes in perceived threat, and subsequent policy guidance and budget allocation, have occurred every several years.

BMD MISSIONS, ERAS, AND DYNAMICS

Prior to 1983, US efforts at ballistic missile defense had mixed direction and few successes. The ABM site at Grand Forks, ND was functional for only a few months before the Congress ordered it closed in 1976 because of cost and operational effectiveness concerns. Pertinent critical research, however, was continued within the military Services, Defense Department, and other federal agencies.

Since 1983, when President Reagan launched his initiative, five broad historical eras can be identified, driven by successive national perceptions of the threat and the distinct missions given to the program by the executive and legislative branches of the government. The years below identify the basic policy breaks. Budget and program implementation breaks invariably come later. *Italics highlight the major differences in the missions assigned.*

- 1984-1987: *Explore* and identify appropriate technologies, and demonstrate the *feasibility of defending the United States* against a *massive Soviet* missile attack
- 1987-1991: *Develop and acquire* a Strategic Defense System (Phase 1) to *deter* a *massive Soviet* first strike *against the US ICBM retaliatory force*
- 1991-1993: Develop a *global* system (GPALS¹) to *protect* the United States and its *allies* from a *limited* ballistic missile attack, *whatever the source*
- 1993-1996: *Develop and field* advanced theater missile defenses in the shortest possible time, and conduct a *national* missile defense *technology readiness* program that would allow a *timely response* to a threat to the US homeland
- 1996-1999: Maintain the momentum on acquiring theater defenses, while *moving national* defense to *deployment readiness* for possible deployment against a *limited* missile attack



Each of these mission developments is discussed in the five eras detailed below.

¹ Global Protection Against Limited Strikes

The Beginnings of SDI – Exploration of Technologies (1984-1987)

Geostrategic Setting. The 1979 Soviet invasion of Afghanistan punctuated a growing chill in US-Soviet relations. In the years between the opening of the US-Soviet strategic arms talks in 1969 and President Reagan's 1983 speech, Soviet advances in offensive nuclear warhead accuracy and numbers called into question the survivability of the US land-based nuclear retaliatory force and, thereby, the confidence that the United States could deter an attack on itself or its allies.¹

American Response. After Congress rejected the deployment of the MX missile, it became clear that another way had to be found to counter growing Soviet first strike systems, and the only alternative was to explore relying on defense. Furthermore, Ronald Reagan argued against total reliance on mutual assured destruction as an appropriate security policy. Two alternatives for active defense seemed to be on the horizon.

First, the Army had begun demonstrating the feasibility of kinetic energy, nonnuclear, hit-to-kill (HTK), and, second, there were a number of indications that directed energy weapons (DEW) might soon be capable of countering warheads. In HTK, a nonexplosive interceptor slams into the target at many thousands of miles per hour,² bringing enough energy directly onto a target warhead to destroy it.³ In directed energy, a revolutionary but less mature technology, a speed-of-light or near-speed-of-light beam destroys a target. The beam might fry a missile's electronic components (a "soft" kill), cause premature explosion (a "hard" kill), or so weaken its structure that it would not survive reentry. Significantly, directed energy weapons might support the high target engagement rates seen to be required against a mass attack of many thousands of nuclear warheads.

In February 1983, the Joint Chiefs of Staff recommended to the President an expanded role for national missile defenses for the United States, and a month later he announced the initiation of the research program to determine whether it would be possible "to save lives [rather] than avenge them."

¹ In the 1970s, the circular error probable of Soviet missiles improved from one half a mile to less than a sixth of a mile. Furthermore, between 1975 and 1980, the number of Soviet warheads increased from 2,400 to 6,000 as the Soviets MIRVed their missile force. About 3,000 of these warheads were accurate enough to constitute a "silo buster" threat to US land-based ICBMs, hence potentially posing a first strike counterforce threat.

² Missile speeds are normally measured in metric units. An arriving reentry vehicle from a long-range ICBM can travel about 7 kms/sec, or about 15,000 mph. Thus, closing speeds with an interceptor could be substantially higher. TMD speeds against short and medium range missiles are considerably less. The greater the closing speed, the more demanding the requirements on an interceptor system. Operationally, this means defenses designed against short-range (slower) missiles cannot successfully engage long-range (faster) ones.

³ One pound of material impacting a target at ICBM closing speeds releases the equivalent of six pounds of TNT. Several early flight experiments bore this out. In June 1984, the Army's Homing Overlay Experiment (HOE) demonstrated the HTK capability in space. The HOE interceptor was a one-ton vehicle that unfolded weighted arms like the ribs of an umbrella, with a deployed diameter of 15 feet. By May 1987, the Army's Flexible Lightweight Agile Guided Experiment (FLAGE) had demonstrated HTK against a tactical ballistic missile within the atmosphere.

Management Structure. Secretary of Defense Caspar Weinberger recognized the difficulty of having the established bureaucratic structure in the Department manage the complexities of such a fundamentally different program and directed that a new agency, SDIO, be set up reporting directly to him. He further prescribed that its Director control a consolidated Pentagon budget for national missile defenses, taking over existing relevant programs in the Services and in federal research agencies, as well as starting appropriate new ones. Because the primary threat was seen as national, there was little attention given to theater missile defenses.

Operational requirements. Concepts of missile defense in the 1950s and 1960s had focused on intercepting incoming warheads using nuclear weapons near the end of their flight paths, because defensive weapons did not have much reach. With the development of multiple warheads, however, terminal ground-based defenses could be overwhelmed by tough, sequential reentry vehicles, requiring, for example, a minimum of ten interceptors for each of the ten warheads on one SS-18 ICBM. At the extreme, tens of thousands of deliberately misleading countermeasures or other objects would need to be sorted and classified – the process of discrimination – to determine the thousands of potential targets from which to select the tens (or hundreds) of targets for intercept. A premium for the defense was put on detecting and beginning the intercept of missiles before they dispensed their warheads. This need drove thinking toward research in space-based architectures.

Architectural Issues.

The original SDI program was based on a study done by the Fletcher Panel¹, which identified eight areas of missile defense technology to be

SDI Technology Program Elements

- Surveillance, acquisition, tracking, & kill assessment (SATKA)
- Directed energy weapons (DEW)
- Kinetic energy weapons (KEW)
- Systems concepts and battle management (SC/BM)
- Survivability, lethality, and key technologies (SLKT)

researched – the content of the SDI program. In 1987, after completing several architectural studies, SDIO settled upon a layered concept that included a battle management system to integrate space- and ground-based sensors and kinetic energy weapons. This system was to intercept attacking missile formations in boost phase through late mid-course. A subsequent ground-based radar and interceptor defensive system would continue to engage any leakers during the missile's terminal flight segment. This initial architectural concept faced several recognized difficulties on which further work was directed.

Architectural Shortcomings

- Weapon system vulnerability
- High cost
- Immature technology
- Command and control complexity
- Attacking missile leakage rates

¹ Headed by Dr. James Fletcher, former NASA Administrator. The Fletcher Panel assessed the state of missile defense technology. A second panel looked at the strategic and policy implications of SDI.

Technological Challenges. SDI's most daunting technical challenges came in infrared (IR) sensor technology for detecting and tracking targets. Other challenges were less pressing – weapons technology development was proceeding at a good pace, and BM/C³ issues could wait until requirements were better defined. Sensors, however, needed to work in ways and in an environment in which they had never before been tested, let alone operated reliably.

While the United States had maintained platforms in space for many years, none had faced the levels of accuracy, precision, dependability, and speed of data processing needed to intercept ballistic missiles in midcourse. Major tests were undertaken to gather the phenomenological data needed to establish the specifications for subsequent systems. The Poker Flats experiment, for example, sent a rocket up through the Aurora Borealis to better understand the effects of radiation on sensors and interceptor guidance and performance. The Delta 180 series of experiments looked at rocket plume signatures, not just to classify them but to determine if (a) sensors could avoid being blinded by them and (b) see through them to find the real target, the hard body of the missile. The captivating images of rocket plumes flowing brightly and hotly back away from launching Space Shuttle vehicles are common stock for today's nightly television newscasts. In outer space, however, with no atmosphere, part of that plume envelops the entire vehicle. Could infrared sensors adequately discriminate between the hot plume and the threat missile body inside? These experiments showed conclusively that they could.

Sensor Phenomenology and Technology Challenges

Technology Focus	Defense Phase*	Improvements Needed	Sensor Type**
Background	B, PB, MC, T	Space, Space-Earth transition (Earth limb), Earth, Clouds, Aurora	SWIR, MWIR, LWIR
Missile Exhaust Plume	B, PB	Physics, especially in space and transition to space	SWIR, MWIR
Target Signature	PB MC T	PB Vehicle, Reentry Vehicle RV, Decoys RV, Decoys, Reentry Physics	LWIR LWIR MWIR, LWIR
Optics	B, PB, MC, T	Cooling (from atmospheric heating), low/stray light, nuclear hardened, wide view, producible, affordable	
Focal Plane Arrays	B PB MC T	Large arrays (± 2000 detectors), high detectivity, electronic readout, signal processing on array, hardened, calibrated, producible, affordable	SWIR, MWIR MWIR, LWIR LWIR MWIR, LWIR
Cryogenic Cooling	PB, MC, T	Long life, cooling for detectors and optics in space	
Signal & Data Processing	B, PB, MC, T	Nuclear hardened, high speed/throughput, robust algorithms, miniaturized, producible, affordable	

* B - Boost Phase
PB - Post-boost Phase
MC - Midcourse Phase
T - Terminal Phase

**SWIR – Short Wave Infrared
MWIR – Medium Wave Infrared
LWIR – Long Wave Infrared

Adapted from John A. Jamieson, 11 Jul 95

Besides the practical realities of seeing and finding the warhead in flight, a stiffer challenge is being able to find it in spite of enemy efforts to hide it. Decoys are among the best known countermeasures, but not the only ones. For example, to thwart a laser weapon, an enemy might cover its missiles with a mirrored surface or spin them, and tests were developed to explore different potential vulnerabilities in defense. One of the early ones, the 1985 MIRACL (Mid-Infrared Advanced Chemical Laser) experiment, decisively destroyed a Titan booster (“like a hot knife through butter”) designed to simulate conditions of a rocket under power. Efforts turned to other countermeasures.

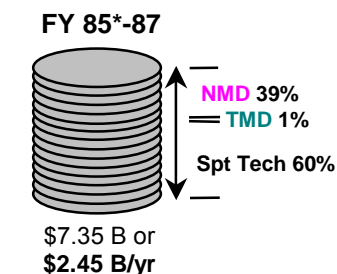
The 1985 Summer Study on BM/C³ identified battle management, command, control and communication as the linchpin of any successful missile defense architecture, and recommended a multiyear technology program to develop solutions for use and growth in a number of areas.

The Summer Study Recommended Work On:

- Orders of magnitude increase in computing speed
- More capable parallel computer architectures
- High speed, space-qualified computer chips
- Adaptive neural networks
- New algorithm designs
- Multilevel security system components
- Highly reliable computer system components

Budget Allocations. When SDIO was established, the nation had already been spending some \$740 million annually on missile defense programs scattered throughout the military Services, defense agencies, and the Department of Energy. SDIO consolidated these under single management. Among the largest of these Service programs were Army interceptor and sensor programs for area and site defense and Air Force satellite programs for missile warning and surveillance.

Throughout the Reagan Presidency, Congress authorized fewer funds than the Administration requested, making the initial program fiscally, rather than technologically, constrained. The SDIO program began with expenditures between practical national missile defense and pure technology exploration in rough balance. By the fiscal year 1987 (1 Oct 86 to 30 Sept 87), technology budgets consumed almost two-thirds of the total. This share included the costs of establishing an extensive infrastructure for BMD research and development.



*The first SDIO Program Budget was for FY85

Major Accomplishments, 1984-1987

- Consolidation of DoD and other Federal BMD R&D
- Coherent, effective SDIO management structure
- Contracts to 7 US and European teams for studies
- Flexible, coherent architecture to guide investment
- Data from pioneering phenomenology studies
- Further confirmation of hit-to-kill (HTK) technology
- Recognition of the difficulty of and a plan for BM/C³
- Widespread net to acquire technologies
- Charter signed to found a National Test Bed

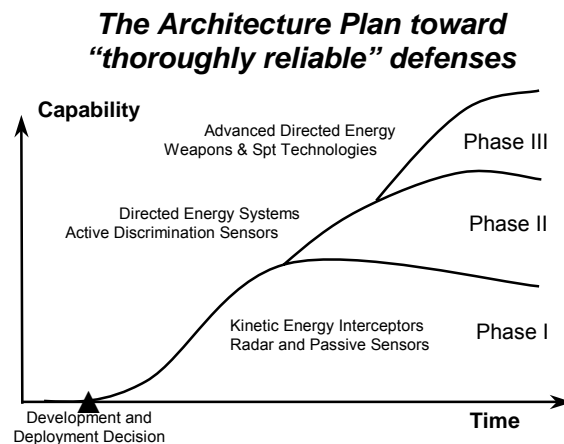
Developing a Strategic Defense System – The Phase 1 Architecture (1987-1991)

Geostrategic Setting. The Soviet strategic force buildup continued through 1987. The 1986 Chernobyl nuclear accident and apprehensions about a nuclear winter raised fresh worldwide concerns over the realities of unleashed nuclear power and costs of nuclear war. Meanwhile, the Iran-Iraq “War of the Cities” in the mid-1980s saw the exchange of several hundred theater ballistic missiles between the two Third World countries, with terrifying effect on both their civilian populations. The ballistic missile era had come of age outside the superpower arena.

American Response. By the end of 1986, Army and SDIO efforts had demonstrated that the principles and engineering of HTK were sound, while directed energy lagged. Work on other aspects of the SDI program also began to yield enough progress that an architecture could be developed to gather all necessary components together into an integrated BMD system. As a result, Secretary of Defense Weinberger directed SDIO to bring the system concept up for formal review as the first step of missile defense. This system, known as the Strategic Defense System Phase 1 Architecture, was approved in September 1987.

Operational Requirements: Operational requirements called for the SDS Phase I system to blunt a massive first strike from Soviet missiles. This would make it impossible for Soviet planners to determine with any degree of certainty how effective such an attack would be. In the strategic realm, uncertainty contributes to deterrence. Additionally, SDS Phase I was to have a high probability of stopping a limited attack. Because the Soviet ICBMs (SS-18s) had multiple warheads, a premium was placed on early interception before warheads could be released.

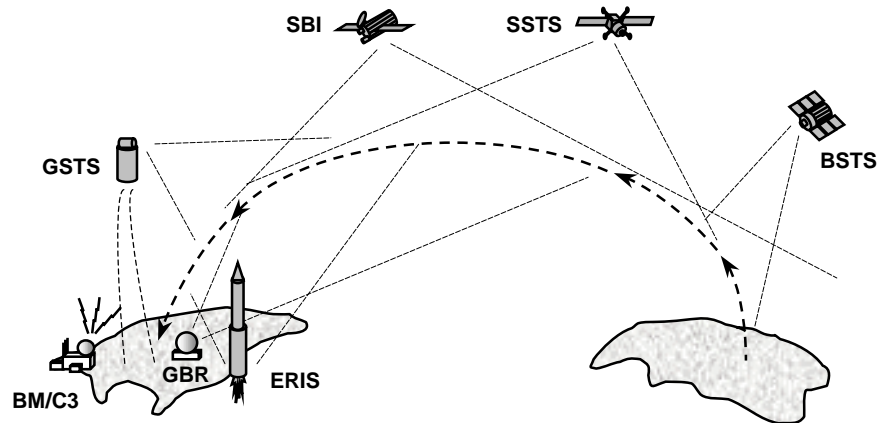
Architectural Issues. The architecture for SDS Phase I was not based on the popular “Star Wars” vision of directed energy beams, but rather on the solid impact of HTK interception. Later phases might build on those concepts, but, like full deployment of Phase I, would require careful consideration of ABM Treaty implications. Testing and deployment of space-based systems was not permitted under the treaty, nor was defense “by other physical principles.”



Six elements in the architecture were approved for SDIO to proceed to the demonstration and validation phase of the DoD acquisition process: three sensor systems, two interceptor systems, and the controlling system:

- The boost surveillance and tracking system (BSTS), in geosynchronous or higher orbit, to detect and track strategic missiles as soon as possible during their boost phase. The system would replace the existing Defense Support Program (DSP).
- The space-based surveillance and tracking system (SSTS), in medium earth orbit for greater sensitivity and accuracy, to detect and track targets in their post-boost and midcourse phases. Sensor requirements for tracking sensors in cold space required a design different from that of the BSTS. It would be a wholly new system.

- The ground-based surveillance and tracking system (GSTS), a pop-up system to be launched upon warning of an attack to discriminate and track reentry vehicles during their midcourse phase.



SDS, Phase I Architecture

- The space-based interceptor (SBI), a platform housing multiple separate HTK interceptor vehicles to engage targets in the boost, post-boost, and midcourse phases of flight, responding to the need for early target interception.
- The exoatmospheric reentry vehicle interceptor system (ERIS), a ground-based HTK interceptor designed for midcourse interception to reach as far forward as possible.
- The battle management/command, control, and communications system.

The number and types of sensors were critical, and not only because of the launch detection warning they might provide. To the extent that sensors could see and keep track of post-boost deployments, they could also relay indications of such events as decoy and chaff release to begin the process of discriminating real warheads from target clutter.

This architecture overcame some of the deficiencies of earlier concepts. Nevertheless, it still had two major drawbacks. The SBI was costly, both individually and as a circling fleet. Enough had to be “on station” (not absent on other parts of their orbits) to cope with an attack. Second, the SBI had to be in low enough orbit to reach rising missiles in their boost phase, but this made them vulnerable to attack by the growing Soviet antisatellite (ASAT) capability. If a single ground-based ASAT could hit one of these SBI “garages” with its interceptors, it would achieve a highly advantageous kill ratio for the attacker.

A solution appeared to come from advances in miniaturization and computational power. Smaller, cheaper, more agile HTK interceptors could be developed (“pebbles,” rather than “rocks”), each containing its own surveillance and control mechanisms (“brilliant,” not just “smart”) and obviating both the need for a vulnerable garage and large missiles.

These autonomous Brilliant Pebbles were originally projected to weigh only 10-25 kilograms apiece, and because they could be deployed in great numbers, could, in theory, have a unit cost cheap enough to acquire. Simulations showed them to be feasible, survivable, and affordable. By the end of this period, SDIO had replaced the Space-Based Interceptor concept with one for Brilliant Pebbles, and research and development proceeded in that direction.

Architectural Shortcomings

- High cost of the total SBI constellation
- SBI vulnerability to Soviet ASATs

A Likely Solution

- Replace SBI with Brilliant Pebbles

Technology Developments. Many of the technologies being developed for SDI were coming together for the Brilliant Pebbles program. While its interceptor design had evolved from Homing Overlay Experiment technology, SDIO’s component miniaturization technology investments significantly reduced its projected weight. This made interceptors less costly to launch and to be maneuvered in space once there.

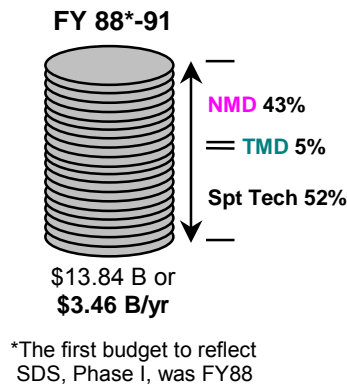
Computational speed had improved, even as volume, weight, and power requirements had decreased. State-of-the-art Cray supercomputers had been roughly the bulk of three large kitchen refrigerators. By the time of Brilliant Pebbles, computers with equivalent power were being reduced to the size of a deck of playing cards weighing a half a pound and operating off less than a thousandth of the power of the Cray.

Communications, for the secure and rapid transmission of vast amounts of data in near real time, could now be handled by a 60 MHz receiver or light emitting diodes weighing 1¹/₃ ounces and using 5 watts of power, rather than the 60-pound instrument of a decade earlier.

Inertial measurement units (IMUs), that serve as the “inner ear” of an interceptor to sense the attitudes and motions necessary to determine precise location, no longer needed mechanical gyroscopes. Now they used the same quartz vibrational technology found in a digital watch, could withstand any realistic g force, and weighed only 0.2 of a pound.

Rocket efficiency, particularly in small engines, made spectacular progress. The second stage engine on an early 1980s Delta rocket had a thrust-to-weight ratio of 60 to 1. By the mid 1980s, the smaller lateral thruster for the High Endoatmospheric Defense Interceptor (HEDI) developed a 930 to 1 thrust-to-weight ratio.

Budget Allocations. Funding during these years was steady until the end of the period, when the overall SDIO budget was reduced by more than 20 percent (see the foldout chart appended). Furthermore, with new emphasis on theater missile defenses, SDIO had to cut both the national missile defense and advanced technology programs to meet this TMD need. Particularly for the technology program, funds were moving out of research and into the demonstration and validation of Phase I components. The proportion of funds devoted to technology support started a long decline.



Major Accomplishments, 1987-1991

- More mature, expandable, integrated architecture
- Major advances in miniaturization and computation power
- Selection of the Brilliant Pebbles concept to replace SBI
- Strengthened approach to early warning and discrimination
- Major experiments, including:
 - Operation of a neutral particle beam in space (BEAR)
 - Laser Atmospheric Compensation Experiment (LACE)
 - Relay Mirror Experiment (RME) to test laser reflection
- Stronger ties with allies, especially Israeli Arrow program
- Activation of National Test Facility near Colorado Springs

Transition – Global Protection Against Limited Strikes (GPALS) (1991-1993)

Geostrategic Setting. Two major events occurred that had profound implications for the SDIO program. The first was the end of Soviet hegemony over Eastern Europe in 1989, followed by the progressive collapse of the Soviet Union itself.¹ Although Soviet nuclear missiles still posed the most significant threat to the United States, the rush to modernize and expand Soviet forces was halted in its tracks, and the likelihood of a massive Soviet attack receded. At the same time, Soviet talent and engineering joined the growing stream of ballistic missile technology proliferating to the Third World.

The second major event was the vividly televised Gulf War, following Iraq's invasion of Kuwait in 1990. Theater ballistic missile attacks on US and allied forces and Israel became a reality, and a hastily modified air defense system, the Patriot Advanced Capability-2 (PAC-2), was rushed into service. While its operational success was limited, the appearance of success had important strategic significance, to include calming civilians subject to missile attack.

American Response. Program emphasis during this period shifted toward developing TMD systems to counter the more immediately recognized theater threat. Efforts to

¹ On 8 December 1991, Russia, Ukraine, and Belarus formed a commonwealth, effectively marking the demise of the Soviet Union.

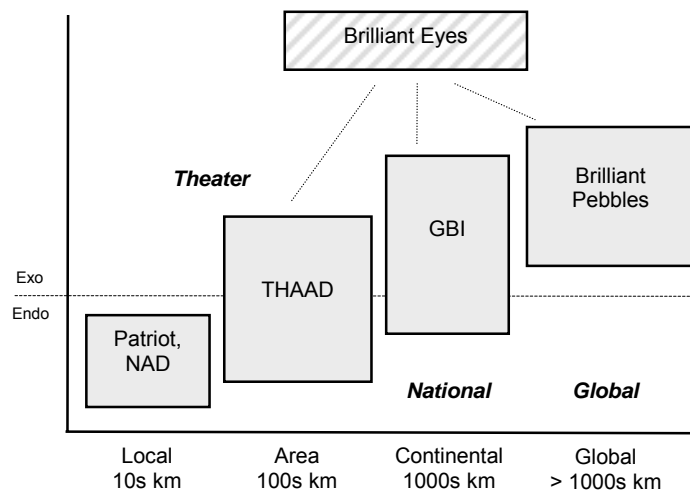
deploy a robust and expensive national ballistic missile defense of the United States dissipated, and the budget and scope of the NMD program were scaled back to a technology readiness development program soon after President Clinton took office.

Congress initiated this shift by passing the Missile Defense Act of 1991, which encompassed both NMD and TMD. It directed the Pentagon to pursue aggressively the development *for* deployment of a limited, ground-based, ABM Treaty compliant, national missile defense by 1996, or as soon as technologically feasible. It simultaneously required the development *and* deployment of advanced theater missile systems by the mid-1990s to defend US expeditionary forces, friends, and allies. Congressional language¹ called for determining a baseline theater missile defense system, including participation by the Air Force and the Navy, not just the Army.

Architectural Issues. Toward the end of his Administration, President Bush directed that the new missile defense focus be Global Protection Against Limited Strikes (GPALS), to protect against accidental, unauthorized, or limited missile attacks. The likely threat had changed from a massive attack on the United States largely from one adversary, to a limited attack anywhere around the globe from any number of countries.

The space-based SDI program elements (sensors, weapons, and BM/C³) were evaluated for their capability under the new priorities for this changed international and American environment. GPALS had three parts – theater, national, and global – all supported by space-based assets, the newest part of which would be Brilliant Eyes (BE), capitalizing on the miniaturization of elements in Brilliant Pebbles (BP):

- The TMD element included the Army's existing Patriot and the developmental Theater High Altitude Area Defense (THAAD) systems. The latter was to operate both in and outside the atmosphere. The Navy Area Defense (NAD) system was to be included, based on existing air defense systems.
- The limited NMD system, using a long-range ground-based interceptor (GBI), would operate in and outside the atmosphere.
- The global component was Brilliant Pebbles.



Major Elements of the GPALS Architecture

¹ See the October 1990 National Defense Appropriations Conference Committee Report for FY 1991.

Brilliant Pebbles would thereby augment deployable theater systems and the ground-based NMD system to create a multi-tiered defense that could provide global defense-in-depth for highly reliable performance at affordable cost.

For TMD, for the first time, several ongoing Service development programs were integrated with the DoD SDI program in 1990. The work included upgrading the Army's existing air defense system, the Patriot, for missile defense, first with a guidance enhanced missile (GEM) and later with a totally new interceptor, the Patriot Advanced Capability-3 (the PAC-3). By contrast, the new ground-based THAAD system was being designed from scratch for an anti-missile role. The Navy Area Defense program, also an upgrade like the Army Patriot, was to be built around the existing and fielded Aegis air defense system. The challenge was to integrate all their operations.

The NMD architecture was scaled back to reflect new conditions: mission change, smaller design threat, and technology advances. Funding for some of the earlier systems was no longer justified. Brilliant Pebbles had replaced the SBI in the architecture, and GPALS now envisioned deployment of only 1000 of these systems, down from the 4000 planned in the SDS Phase 1 architecture.

The acceptance of Brilliant Pebbles also brought other changes. Since the newer BP system had its own sensors for surveillance, warning, and tracking, the BSTS was no longer essential and was removed. Also removed was the SSTS, since it was vulnerable to ASATs and neither Brilliant Pebbles nor the ground-based interceptor systems under development needed it. Similarly, SDIO eliminated the GSTS system, part of the earlier architecture, as unaffordable and operationally dubious, especially since it provided only an interim coverage before BP was expected to be available a few years later.

Evolution of Needed Sensors

<i>Defense Phase</i>	<i>SDS Phase I*</i>	<i>GPALS</i>
Boost	BSTS	BE, BP
Post-boost	BSTS, SSTS	BE, BP
Midcourse	SSTS, GSTS	BE, BP
Terminal	GSTS	GBR

* Discussion of these sensors is found on pp. 19-20 above.

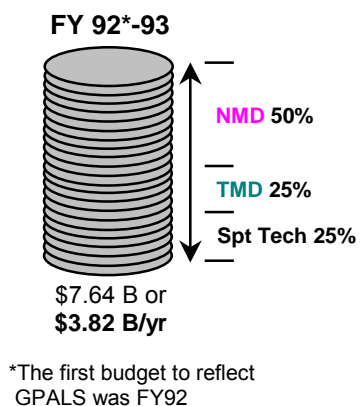
Technology Developments. Sensor design progressed as fast as interceptor design, especially in the critical infrared spectrum. Infrared sensors were especially valuable because they were passive (not active, like radar), low in mass and power consumption, and useful throughout all phases of an attacking missile's trajectory. Critical technologies for midcourse discrimination in mid- and long-wave infrared sensors were demonstrated. Technologies were developed for cooling interceptor sensor windows, located in nose cones and heated by the atmosphere, so infrared or optical sensors could be effective. All the while, processing technology, in smaller packages, advanced to unprecedented levels.

In addition to technological developments, the US missile defense program collected a large data base on signatures of rocket motors, gas plumes, reentry vehicles, and, importantly, backgrounds, especially potential nuclear backgrounds. This multispectral phenomenological data base was important for computers to make real time comparisons

of signatures for reliable identification, not just detection, of events and objects. There could be no room for error and no time for false alarms, for example, in discriminating between a missile launch and sunlight scattered off high clouds.

As these issues were being tackled, engineering and BM/C³ issues remained immense. As Lieutenant General George Monahan, the second Director of SDIO, said in his 1990 report to the Secretary of Defense, “The greatest engineering, vice technical, challenge in the SDI Program is software, with about 20-30 million lines of code required for Phase I.”

Budget Issues. The missile defense budget was again sharply reduced for FY91, with NMD funding cut by 20 percent from the previous year. The space-based elements (BSTS, SSTS) were passed to the Air Force for continuation of research on its elements, while the Army’s GSTS program was cancelled. As can be seen from the foldout chart at the end of the paper, major funding shifts occurred to support the national priority now accorded to TMD. In FY90, funding for TMD was \$131 million. Four years later, Congress voted to spend \$1,646 million on it, a twelve-fold increase. Funding also continued to shift out of technology development programs, as evidenced by a 50 percent cut between FY1991 and FY1993.



Major Accomplishments, 1991-1993

- Shifted architecture & management for new missions
 - Developed concepts for seamless defense coverage from local to global
- Created Theater Missile Defense baseline
- Established a coherently managed joint program with Service assets
- Expanded phenomenology data base
- Demonstrated critical technologies for mid- and long-wave IR sensors

The Primacy of Theater Missile Defense (1993-1996)

Geostrategic Setting. During this period, the probability of a massive Russian missile attack continued to abate and an attack by China on the United States seemed remote. Nevertheless, concerns about theater attacks mounted. In 1993, North Korea sent an intimidating missile into the waters near Japan; India and Pakistan tested their own missile delivery systems; and proliferation of missile technology, especially Scud derivatives, was increasing. In 1996, China punctuated a political message by firing four missiles near Taiwan, bracketing the island just before Taiwanese elections.

American Response. The newly elected Clinton Administration instituted a Bottom-Up Review (BUR) of defense requirements for the post-Cold War era. To signal the change in focus for the missile defense program to embrace the theater level, Secretary of

Defense Les Aspin changed the name of the SDIO to the Ballistic Missile Defense Organization (BMDO). The new BMDO was given three specific missions:

- The primary goal was to *field TMD systems* as quickly as possible, a develop-and-deploy mission.
- The second was to provide the *basis for a speedy decision to deploy NMD systems*, should a serious threat to the US homeland appear, a technology readiness mission.
- The third was to *continue with advanced technology* development to enhance existing and future TMD systems and to support NMD technology readiness, thereby to counter existing and emerging threats.

As the Soviet threat continued to recede, Congress amended its 1991 act with the Missile Defense Act of 1993 to push the program further toward theater defenses. It eliminated the requirement for fielding a national missile defense, emphasized compliance with the 1972 ABM Treaty, and relaxed the time strictures on fielding theater systems.

Architectural Issues. In contrast to the preceding periods, there was no single architecture for a unified missile defense; instead, there was one for TMD and another for NMD.

TMD. Due to the complexity and diversity of the theater missile threat, no one Service, and certainly no one weapon or sensor system, could accomplish the mission alone. Thus, the TMD program consolidated separate, ongoing Service development programs under a single theatre architecture. The Department gave BMDO the responsibility to ensure that any systems developed could be integrated into a seamless operational structure, rather than merely being capable of working side-by-side. Effective TMD required interoperable systems that could “talk” to each other, passing data and triggering responses using standard communication links and procedures. Both land- and sea-based weapons systems might be needed to cover likely scenarios of engagement at each level of capability. Each system used its own independent sensors, although some data would be passed from space-based assets once connections could be made. There were four core development programs:

- In the lower tier (endoatmospheric), the Army’s Patriot program (PAC-3) and the Navy Area Defense (NAD) program.
- In the upper tier (exoatmospheric), the Army’s THAAD program and a fourth program, eventually the Navy Theater Wide (NTW) system, to round out the core.

Two other systems, MEADS¹ and ABL,² were also being explored for possible development, although they were not yet part of the core program.

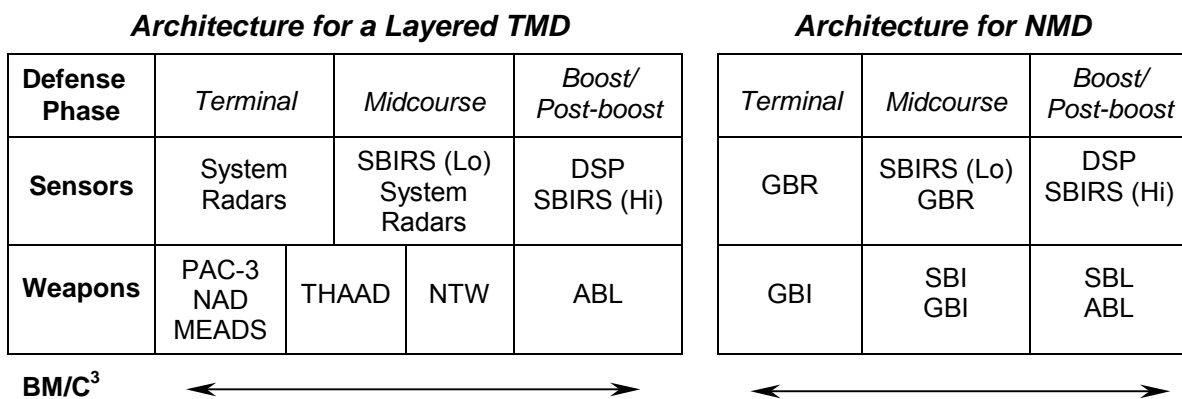
¹ The Medium Extended Air Defense System, formerly the Army’s Corps Surface-Air Missile (Corps SAM), a cooperative program with Germany and Italy, was being designed to meet NATO requirements for mobility and 360° protection of maneuver and deployed forces.

² The Airborne Laser, an Air Force system, had a multimewatt chemical laser for boost phase kill.

ABM Treaty issues for TMD now came into sharper focus because THAAD and Navy Theater Wide were being designed with exoatmospheric capability that could, theoretically, be employed against strategic ballistic missiles. In 1997, a US-Russian agreement was reached (although not ratified), as discussed above, on demarcation between TMD and NMD for theater missile defense systems which clearly do not have capability against strategic ballistic missiles.

NMD. The NMD program took a 70 percent cut in funding between 1993 and 1994, requiring a complete overhaul and restructuring of the program. Central to this cut was the fact that Brilliant Pebbles, around which so many earlier changes had been fashioned, was removed from the architecture, and its sensor and miniaturization technology was transferred to other programs. Costs were rising, not all operational control issues had been resolved, and, as a space-based weapon, both Congress and the Department directed that it be removed and that a treaty compliant (i.e., ground-based) interceptor replace it. Brilliant Pebbles reverted to reduced funding research status, and management responsibility was transferred to the Air Force in 1993. Other sensor budget casualties included the FEWS¹ and Brilliant Eyes. They were evolving into a future two-layer system, the Space-Based Infrared System (SBIRS) High and Low. The less capable but already operating DSP² was maintained and enhanced to the extent possible.

To cope with the potential for a quick deployment if a sudden (and uncertain) threat emerged, the NMD program was refocused on a ground-based architecture (with ground- and space-based sensors, a ground-based interceptor, and BM/C³) to preserve the integrity of the subsystems and place emphasis on continuing to tackle the most difficult technical problems. It provided for three successively more capable deployment options. It was based on the premise that the later a decision was made to deploy, the more capable would be the system to be fielded.



¹ FEWS (Follow-on Early Warning System) was to be a geosynchronous satellite system that could perform a tactical warning and attack assessment function, with significant on-board computing power. It was to be a global surveillance system to track missiles in their boost phase. It would cue the Brilliant Eyes, designed as a midcourse sensor to pick up missiles after burnout and above the atmosphere.

² The DSP (Defense Support Program) is a constellation of satellites in geosynchronous orbit (some 23,000 miles above the earth's surface), initially launched in 1970. The DSP satellites are linked to ground stations and provide missile launch warning and limited tracking capabilities.

Technology Developments. Technologies rooted in the SDIO program fed directly into both the TMD and NMD programs, but with slightly different emphases because of the separate origins of the various elements. By this time, most of BMDO's funds were going toward the early stages of program acquisition for systems rather than program research. Previously developed system prototypes were being "weaponized" to ensure they would perform reliably under field conditions. Successful technologies developed in university laboratories needed to be transferred to manufacturing company floors to build complete systems. Manufacturing tools and lines had to be designed and built.

The advanced technology portion of the missile defense program now represented only 15 percent of the BMDO budget. The technology research program consisted of the Small Business Innovative Research Program and Space-Based Laser (SBL) programs and a variety of applied rather than basic research programs, taking three-fourths of the research allocation. This period began the transition from future technology investment to exploitation and incorporation of past technology investments into systems. The success of these technology insertions validated SDIO's/BMDO's prior investment strategy.

TMD. The TMD program leveraged prior technologies as much as possible. The PAC-3 missile was being developed using the technology from the Extended Range Interceptor (ERINT) program for its HTK capability. ERINT had itself emerged from FLAGE¹, an earlier SDIO-Army program of the mid-1980s. These technologies in turn capitalized on earlier Army small radar homing intercept technology (SRHIT). During tests in 1993 and 1994, ERINT scored successive direct hits on a number of targets representing weapons of mass destruction.

ERINT Intercept Successes Against:

- A target with 38 pressurized containers designed to simulate toxic chemical submunitions
- A simulated unitary chemical warhead
- A maneuvering, air-breathing cruise missile drone

The technologies themselves were evolving rapidly. An example was a more advanced inertial measurement unit. This technology, however, has been another "moving train" in the continuous effort to miniaturize and enhance performance. What had been a state-of-the-art, lightweight ring laser gyro unit in the 1980s (replacing the earlier mechanical gimbaled gyro), evolved into a solid-state fiber-optic gyro, then to a quartz tuning fork gyro, to a micro-mechanical gyro. By the mid-1990s, the instrument's size had shrunk from 0.47 to 0.17 cubic inches and its weight had dropped from about 4 ounces to less than half an ounce – about the size of a grain of rice. (This trend illustrates what can be a significant issue in any cutting edge program: when to freeze technology design.)

More weight savings were possible by using ceramic radomes. These had the added benefit of being more transparent than earlier protective coverings. Similarly, the PAC-3 was being designed with 180 miniature rocket motors in a belt around its frame to provide far more responsive maneuvering – and accuracy – than could the earlier PAC-2 with its aerodynamic fins.

¹ Flexible Lightweight Agile Guided Experiment

The Navy Area TMD program was upgrading the Navy's Aegis air defense system, thereby capitalizing on the more than \$40 billion already invested. Modifications were needed for software and hardware, including radar systems. The BMD program provided enhancements to the Standard missile, involving seeker improvements in track processing, aim point selection, and window cooling technology.

Upper tier systems also profited from SDIO/BMDO-sponsored technologies. THAAD interceptor designs built on HTK technology culled from a variety of sources – the Advanced Interceptor Technology, Brilliant Pebbles, Space-based Rail Gun, ERINT, HEDI, and ERIS programs.¹ The seeker window, a sapphire plate, was developed from HEDI, as was the focal plane array seeker itself. Navy Theater Wide was being built on the Navy Area baseline, also using the Aegis weapon system as foundation. Its HTK missile evolved from the Lightweight Exoatmospheric Projectile (LEAP), an advanced miniature SDIO technology developed earlier for a space-based, rail gun application. The attached foldout chart illustrates the lineages.

NMD. NMD systems similarly capitalized on prior or parallel development. The ground-based radar (GBR) prototype for NMD used a demonstrator leveraging directly off progress in the TMD radar program. This approach allowed program concentration on the longer range requirements of NMD, while resolving issues shared by the TMD system in a cost-effective manner. The program for the X-band, phased array radar evolved from the mid-1980s to develop software operations, applications processing, and new radar imaging techniques. Passive infrared sensors developed for the defunct Army GSTS and Brilliant Pebbles programs facilitated development of the Air Force's Space-Based Infrared System (Low). Advanced beryllium optics and tracking algorithms were transferred from ERIS and HEDI to the NMD kill vehicle.

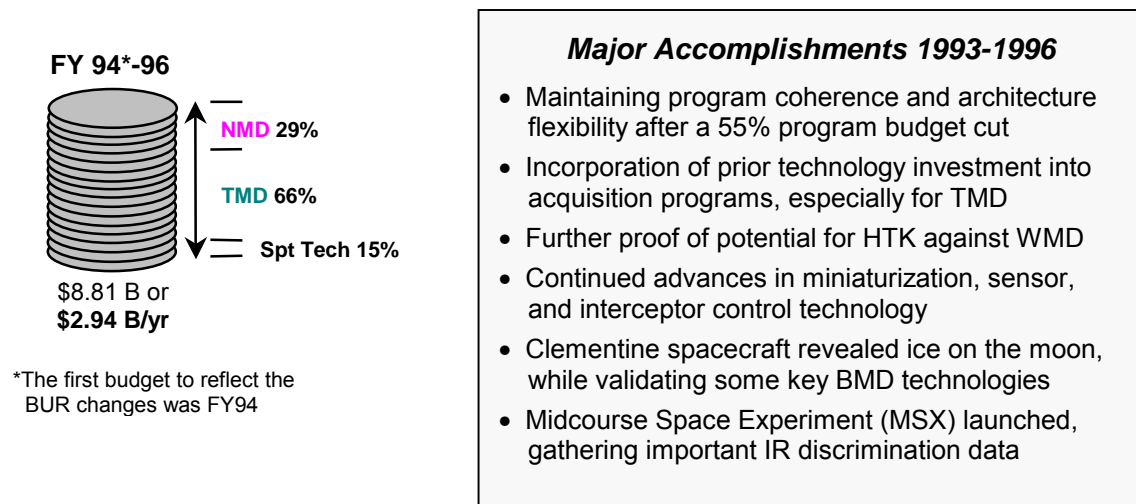
The NMD ground-based interceptor (GBI) program built on the several decades of legacy in HTK effort. Principal among these were the Army's HOE exoatmospheric interceptor and the subsequent ERIS program. Guidance and control elements, such as the gyro, benefited from LEAP and Brilliant Pebbles in lighter weight, lower cost, and improved performance. Infrared focal plane array technologies confirmed the ability to produce the long- and very long-wavelength detectors needed for the GBI. Radiation hardened electronics demonstrated low fault tolerance and low power consumption with higher processing throughput. Other carryovers from Brilliant Pebbles, such as propulsion and on-board computing, were included in future TMD and NMD applications.

Budget Allocation. The overhaul of the missile defense program requirements was accompanied by a major realignment of BMDO's resources, as is reflected in the foldout chart. The FY94 BMDO budget was cut by a quarter, while the TMD program portion was increased substantially. NMD paid most of the bill, with the program very sharply

¹ ERINT – Extended Range Interceptor
HEDI – High Endoatmospheric Defense Interceptor
ERIS – Exoatmospheric Reentry Vehicle Interceptor System

downsized from \$1,886 million in FY93 to \$553 million in FY94, and downgraded from an acquisition program to a technology readiness program.

The BMDO five-year program plan saw more dramatic reductions. The previous plan of \$39 billion was now cut to \$18 billion. In spite of the fact that its budget expectations were reduced by more than half, BMDO successfully restructured and redirected its multiyear acquisition programs. Of the \$18 billion, \$12 billion was slated for TMD acquisition programs, \$3 billion for NMD, and the remainder for advanced technology. Continued investment in the latter was important to support ongoing programs and to provide a hedge against future threats. This major realignment task, accomplished by BMDO and its Director, Lieutenant General Malcolm O'Neill, merited the Department's Joint Unit Meritorious Award, which was presented by Secretary of Defense William Perry in February 1996.



The Re-emergence of National Missile Defense (1996-1999)

Geostrategic Setting. This next period could be called the “rogue nation” era for missile defense. As Russia and China remained in “uncertain transitions,”¹ the threat from Third World countries seemed more mature and more threatening not only to American friends, allies, and deployed forces abroad, but also to the American homeland. The effect of missile proliferation began to be very noticeable. In 1972, when the Anti-Ballistic Missile Treaty was signed, only two nations outside the geographic boundaries of NATO and the Warsaw Pact had operational ballistic missiles – Israel and China. By 1985, that number had grown to ten. During the period reviewed here, it grew to 16.

The dangers of proliferation were compounded by steady increases in the range and potential payloads of ballistic missiles around the world. Missiles had become the currency of international prestige, and having them conferred for the holder a claim to a

¹ Report of the Commission to Assess the Ballistic Missile Threat to the United States (Rumsfeld Commission), July 15, 1998.

seat at the table with the major powers – the more so if his missiles could reach those powers.

What had been a relatively clear distinction between TMD and NMD began to blur as the TMD threat matured in range and sophistication beyond limited Scud-like capabilities. Furthermore, it became clear that Russian control over former Soviet missile technology and weapons of mass destruction could not be taken for granted.

In July 1998, a congressionally appointed commission, chaired by former Secretary of Defense Donald Rumsfeld, provided a sobering analysis of the nature of the threat and the limitations of the nation's ability to predict how rapidly it could change. A few weeks after the Rumsfeld Report was issued, on August 31, North Korea launched a Taepo Dong-1 missile. Billed as a space launch vehicle, it overflew Japan and demonstrated important aspects of intercontinental missile¹ development, especially multiple stage separation and – unexpectedly – the use of a solid-fueled third stage. The test was another strong indicator of the threat that could soon face all 50 states of the American homeland. The more advanced Taepo Dong-2, the prospective test flight of which became an international issue during the summer of 1999, appears to have an even greater range and payload capacity.

American Response. During this period, as the TMD program continued to evolve, NMD issues came to dominate the US missile defense program once again. By the end of 1996, the Office of the Secretary of Defense had transformed the NMD program to reflect the growing threat by adopting a more specific schedule for development and deployment known as the “3+3” program. The planned NMD system stayed within the treaty limits of no more than 100 ground-based interceptors and would therefore be incapable of countering a massive attack from Russian missiles. It was intended, however, to offer highly reliable protection against a smaller number of missiles from a hostile Third World power or an accidental or unauthorized launch from Russia or China.

The revised program called for three more years of development and testing, followed by a deployment readiness review (DRR) set for 2000. If deployment were warranted, initial capability could be available by 2003.

If the threat did not warrant deployment, the NMD development program would

Progressive Development of a Limited NMD Capability

- C1 A few missiles, with relatively simple warheads
- C2 A few missiles, with some countermeasures
- C3 A larger number of missiles, with sophisticated countermeasures

continue toward an objective system more capable than one that could have been fielded in 2003. At any time after 2003, the United States was to be able to field an NMD system within three years of a decision to deploy.

¹ A ballistic missile is classified as intercontinental if it has a range of over 5,500 kms.

Following the 1998 North Korean missile test, Secretary of Defense William Cohen announced on 20 January 1999 the decision to fund fully the development and potential deployment of a National Missile Defense system over the Future Years Defense Program (FYDP), adding \$6.6 billion to the FYDP budget request to do so. He announced the adoption of a phased decision process that would reduce schedule and technical risk. He also announced that the potential deployment date had been shifted to 2005 to further reduce schedule risk.

The revised program called for specific decisions at various times following the 2000 Deployment Readiness Review, should the President decide to move forward to field an NMD system. The additional time allowed for developing the Ground-Based

<i>Planned Earliest NMD Milestones</i>	
2000	Deployment Decision Review Site and construction decision
2001	Ground-Based Radar and BM/C ³ decision
2003	Ground-Based Interceptor decision
2005	Potential operational NMD

Interceptor would be used to conduct seven more flight tests prior to making an interceptor production decision. The additional testing would significantly reduce technical risk and increase confidence. Each subsequent decision point was timed to coincide with achieving specific developmental or performance goals, moving toward an event-driven, rather than schedule-driven, program.

To reduce program risk further, the initial C-1 deployment that was to be accomplished by 2005 was reduced to 20 interceptors at one site, with the full 100 scheduled for 2007. This latter configuration was called Expanded C-1.

Meanwhile, Congressional interest in NMD led to the passing of the National Missile Defense Act of 1999 which the President signed in July. This law made it “the policy of the United States to deploy as soon as is technologically possible an effective National Missile Defense system capable of defending the territory of the United States against limited ballistic missile attack (whether accidental, unauthorized or deliberate)” and to seek continued negotiated reductions in Russian nuclear forces.

Architectural Issues. The architectures for both TMD and NMD remained virtually unchanged.

TMD. The TMD Family-of-Systems architecture included the following programs:

- Three lower tier systems: PAC-3, MEADS (initially to leverage off the PAC-3 missile), and Navy Area Defense.
- Two upper tier systems: THAAD and Navy Theater Wide.

- Two parallel Air Force funded programs: the Airborne Laser (ABL) and the Space Based Infrared System (SBIRS)¹.
- A Battle Management/Command, Control, and Communications (BM/C³) system.

The Israeli ARROW program, developed with US support and based on a focused high explosive warhead rather than a kinetic energy (HTK) design, was a parallel international effort now nearing operational capability. In an August 1996 early intercept test flight, it successfully destroyed another target missile.

NMD. The NMD system elements included various configurations depending on the specific future threat it was designed to defeat. Its essential components are:

- *Ground-based Sensors.* There were two major programs. The first was Upgraded Early Warning Radars (UEWRs), based on existing Pave Paws and BMEWS systems, that were used largely to detect threatening missiles and to track other space objects. The second was the X-Band Ground-Based Radar (XBR or GBR). This phased array radar conducts its tracking sweeps electronically, very much faster than traditional radars that rotate their antennas mechanically. Forward basing and the short wavelength of the X-Band provide very high resolution data for identifying, tracking, and discriminating in the early phases of an ICBM's trajectory and supports early interceptor launch. The XBR, for example, can detect an object the size of a golf ball some 2,400 miles away, or the distance between Washington, DC and Seattle.
- *Space-based Sensors.* The current system is the Defense Support Program (DSP) satellite system. That will be replaced by the Space Based Infrared System (SBIRS High for the initial NMD deployment, to provide space-based missile launch detection, surveillance, and track data. Later, the lower-altitude satellite (SBIRS Low) system will be added to provide more discrete identification, discrimination, and tracking capabilities early in the missile's flight path and, ultimately, kill assessment of the payload. Together, these two systems will provide more advanced performance to counter more sophisticated future threats and countermeasures.
- *Weapon.* The Ground-Based Interceptor (GBI) is based on an enhanced booster stack, made from several capable commercial, off-the-shelf rocket stages. Its Exoatmospheric Kill Vehicle (EKV) is a kinetic energy, exoatmospheric HTK interceptor designed to engage ballistic missile warheads in midcourse.
- *Battle Management/Command, Control, and Communications (BM/C³) Element.* This element consists of the hardware, software, communications, and facilities necessary for planning, tasking, and controlling the NMD system. The BM/C³ center will be located at the Cheyenne Mountain Complex in Colorado and will ensure positive human control over all aspects of NMD.

¹ In its theater support role, the SBIRS system is being designed to be able to report warning of ballistic missile launches to affected theater forces, and to provide technical intelligence, battlespace characterization, and critical midcourse tracking and discrimination data for terminal defenses.

Technology Developments. Advanced technology efforts have been directed along three major lines: surveillance, interceptors, and BM/C³.

Regarding surveillance, an important experiment was initiated during the prior period in 1996 and continued down to the present. This is the Midcourse Space Experiment (MSX) which, for the first time, demonstrated a space-based, long wave infrared surveillance and discrimination capability. In so doing, it was a key step in validating the expected performance of the SBIRS Low satellite system. The MSX was also the first satellite to demonstrate such a surveillance capability from space (rather than the ground), important because SBIRS Low is designed to support not only NMD, but also TMD systems.

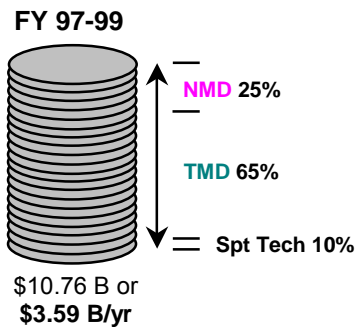
Regarding interceptors, during this period, they continued to validate the HTK performance for which they were designed. Five of the last six intercept flight tests in 1999 resulted in successful intercepts demonstrating capability for lower tier and upper tier TMD weapons and the NMD system (see box below). As programs continue, future testing will become progressively more complex and more operationally realistic to demonstrate the integration of all system components in a variety of increasingly demanding scenarios.

Technology projects have proceeded with an eye toward the evolving threat. A central thrust has been devoted to countermeasures to stay several steps ahead of foreign ballistic missile technology. Nevertheless, the share of the BMDO budget for advance technology dropped below ten percent. This level of expenditure indicates that SDIO/BMDO has completed its initial mandate to investigate the technical feasibility of providing an effective ballistic missile defense. The challenges have become engineering and reliability, rather than basic science and technology.

The years of technological investment have produced significant benefits. In early 1999, for example, Dr. John Peller, Vice President and Program Manager for Boeing's NMD Program at the time, told the Congress: "One thing that's truly unique to this program is the tremendous investment by the Ballistic Missile Defense Organization and the technology for this program. I have never entered a program of this type with the underlying technology as mature as it is for this program. All those dollars invested over the years have given me the best set of building blocks to start with that I have ever had."¹

Budget Allocation. The requested addition of \$6.6B to the NMD funding level for the FY99-05 FYDP budget, brings the NMD total to \$10.5B for those years. Included in the budget is \$600 million that was provided by Congress in the FY99 supplemental appropriations bill. The added funds were to allow the completion of the development of the NMD system and fund deployment of the initial system by 2005.

¹ 24 February 1999, before the Strategic Forces Subcommittee of the Senate Armed Service Committee.



Major Accomplishments 1997-1999

- Maturing ballistic missile system capability, as evidenced by successful HTK intercepts in 5 tests by 3 different systems:
 - 2 tests by PAC-3 (Mar 15 and Sep 16, 1999)
 - 2 tests by THAAD (Jun 10 and Aug 2, 1999)
 - 1 test by NMD EKV (Oct 2, 1999)
- Restructured TMD upper tier programs for affordability
- Strengthened dialogue with operational community for refining requirements and reinforcing interoperability
- Saved an estimated \$4.3B in life cycle costs by contracting for an experienced NMD Lead System Integrator
- Continued technology infusion into TMD and NMD

The Road Ahead (2000 – 2007)

Geopolitical Setting. All projections of the threat point in the same direction as that spelled out in the Rumsfeld Report and the intelligence community's 1999 ballistic missile threat assessment.¹ Those nations of concern, having active missile building and testing programs, seem bent on increasing the range and capability of their missiles. Emerging missile powers such as North Korea show little sign to date of permanently ceasing their endeavors to develop and sell ballistic missile capability. Suggestions that he might have offered a deal to do so were "laughingly" dismissed by Kim Jong Il.

The rattling of test missiles and nuclear warheads between India and Pakistan is unsettling for South Asia, yet has implications well beyond the region. Iran's development of the Shahab-3 missile, with a range of over 1000 kms, similarly has significance beyond its neighbors in the Middle East. The overall theater threat is expanding into a global one, one which includes the United States.

Even established nuclear powers are not immune to the use of missiles in support of their diplomatic goals. In 1999 during the Kosovo crisis, Russia pointedly and publicly renounced the no-first-use pledge made by the Soviet Union, and China broke its normal silence on such matters to announce it had tested its Dong Feng-31 solid rocket ICBM booster. Earlier, during demonstrations over Taiwan independence, the PRC had alluded to its ability to reach Los Angeles with ICBMs. Clearly, missiles are now tools used for signaling displeasure with aspects of US foreign policy. In different circumstances, the brandishing of missile capability could be used to coerce America or its allies, thereby influencing decisions on US policy options.

¹ "Foreign Missile Developments and the Ballistic Missile Threat to the United States through 2015," CIA, September 1999.

American Response. Based on the Missile Defense Act of 1999, the United States is “committed to addressing the growing danger that rogue nations may develop and field long-range missiles capable of delivering weapons of mass destruction against the United States and our allies.”¹

Architecture Issues. To meet that threat, BMDO continues two far-reaching programs.

TMD. There are now five basic programs in the Family-of-Systems that comprise the comprehensive TMD architecture, with land- and sea-based systems for terminal and midcourse intercept. An airborne laser system that could provide boost phase intercept in some future scenarios is being developed.

NMD. The current architecture is very flexible, with the ability to build more sophistication into the NMD system without fundamental changes to its building blocks. This approach was validated in a recent report by an independent review team headed by retired Air Force General Larry Welch. The team’s June 2000 report pointed to the critical attention needed to address potential countermeasure challenges, but also noted the “extensive potential in the system to grow discrimination capabilities.” This growth potential has maximized the ability to field capable systems against a wide range of numerically limited threats, from simple to complex.

The Technology Base. The advanced technology program is essential to maintaining the continued effectiveness of both TMD and NMD in the face of threats that will surely advance over time. The program continues to emphasize three main avenues of research: sensors, weapons, and BM/C³.

- **Sensors.** The Advanced Radar Technology program is focused primarily on anticipating and overcoming countermeasures that might impede the identification and discrimination functions required for a successful intercept. Its results would feed directly into TMD and NMD radar programs. Infrared sensor technology and discrimination algorithms being developed for the SBIRS Low satellite address some of the more difficult countermeasure issues.
- **Weapons.** The Space-Based Laser (SBL) remains the major effort in far-term weapons research. A recent review recommended integrated ground demonstrations for key technologies and flight control system elements. A later orbital experiment could test large lightweight optical mirrors that could significantly reduce on-orbit weight and produce dramatic cost savings.

Two other important thrusts are the Atmospheric and Exo-atmospheric Interceptor Technology programs (AIT and EIT respectively). The AIT program works on upgrading endoatmospheric HTK technologies and reducing costs in existing TMD programs. The EIT program focuses on developing advanced seeker concepts and materials to improve the ability of interceptors to discriminate, identify, and close on the right exoatmospheric

¹ President William Clinton, as he signed the Act into law on 23 July 1999.

target. In addition to work on passive interceptor sensors, research is being done on active discrimination and tracking approaches using ladars (laser detection and ranging) that could fit onto interceptors.

- BM/C³. The goal of this program is to improve existing algorithms and techniques of control over the complex systems developed for both the TMD and NMD programs. Simulations, continuous testing, systems engineering, and systems integration are being used to forge components into a single operational NMD system.

Research on better manufacturing technologies and methods is another facet of the program that promises good future payoff, especially as a number of systems are now reaching developmental maturity. Decisions about full-scale production are near at hand.

The Next Steps. The foldout chart illustrates the variety of major programs from which BMDO is fashioning America's ballistic missile defense. Linkages show the primary predecessor programs with promise. Current programs are capitalizing on the lessons learned, technologies that have matured, and components proven for use in systems that are now moving through the later phases of their normal acquisition cycles, from prototypes, through development, into production. Over the next few years, management responsibilities will be transferred to the Services as the systems will be fielded based on decisions yet to be made.

The investment and acquisition approach of the past sixteen years is now bearing fruit. Over the next eight years, the Army's PAC-3 and THAAD systems and the Navy's Area and potentially Theater Wide systems stand to become operational with at least a limited initial capability. The Air Force intends to demonstrate the feasibility of short-range ballistic missile engagement by its airborne laser. The MEADS system, which is internationally managed, should be fielded sometime after 2007.

In TMD, fielding a lower tier capability in the near term has been first priority. For the upper tier, the phased introduction of increasing capabilities (a "block approach") will reduce program risk and hasten the fielding of operational systems.

On the other hand, the NMD system has suffered failures in both intercept flight tests conducted during 2000 and delays in some key program elements, especially booster development. On September 1, 2000, President Clinton decided to defer to his successor any decisions to start deployment actions and instead directed the continuation of a robust NMD development program. A reassessment of the program schedule for deployment is underway.

BMD Systems Scheduled for Possible Deployment by 2007*

- Patriot PAC-3
- Navy Area
- Theater High Altitude Area Defense
- Airborne Laser
- National Missile Defense

*Contingent on Administration and Congressional approval

CONCLUSION

Over the past sixteen years, the history of the ballistic missile defense program has been marked by wide variations in perceived threat, mission, guidance, focus, technical challenge, and resource allocation.

Policy Focus	Research	SDS, Ph I	GPALS	TMD	TMD & NMD
<i>Timeframe</i>	1984-87	1988-91	1991-93	1993-96	1997-2007
<i>Mission Emphasis</i>	Protect against massive Soviet strike (1000s of warheads)	Deter against massive Soviet strike	Protect against limited attack from anywhere (100s of warheads)	Defend deployed forces, allies, & friends	Tactical and limited national requirements (NMD: 10s of warheads)
<i>Element Focus</i>	Early Warning Space	Space	GBI Brilliant Pebbles	Terminal interceptors	Midcourse sensors & GB interceptors
<i>Key Unresolved Technical Issues</i>	Feasibility & Environment	Survivability & Discrimination	Initial deployment of weapons	Lethality against targets	Lethality, Discrimination, Integration

However, throughout this period, the Ballistic Missile Defense program has remained responsive to the needs of the nation, adjusting as those needs have changed, and redirecting the scope and focus of the program as necessary.

SDIO and BMDO have overcome major technological challenges, winnowing early concepts down to those that proved feasible and affordable, and sponsoring and realizing major advances in the relevant technology. The basic technologies for operational systems have now been demonstrated. The challenges of the program are now engineering and production ones – integrating multiple complex systems into larger operational wholes, ensuring that costs of production remain fully under control, and ultimately providing fielded systems for national and theater defense.

These efforts all have the goal of ensuring the safety of America's people, her forces, and her international friends, thereby supporting US interests. Past programs are now bearing fruit in the development of operationally effective and cost-effective systems.

With the backing of the Administration and the Congress, by 2007 the United States could have, for the first time, effective, globally deployable theater missile defenses and a significant national missile defense capability. These systems will be able to protect against a limited ballistic missile attack and, importantly, deny hostile nations the ability to blackmail the United States or its allies.



ABL	Airborne Laser	ERINT	Extended Range Interceptor	JCTN	Joint Composite Tracking Network	SAM	Surface-to-Air Missile
AIT	Advanced Interceptor Technologies	ERIS	Exoatmospheric Reentry Vehicle	JDN	Joint Data Net	SB1	Space-Based Interceptor
ALARM	Alert, Locate, and Report Missiles		Interceptor Subsystem	JPN	Joint Planning Net	SBIRS	Space-Based Infrared System
AOA	Airborne Optical Adjunct	EWR	Early Warning Radar	JWID	Joint Warrior Interoperability	SB1	Space-Based Laser
AOS	Airborne Optical Sensor	FEWS	Follow-on Early Warning Radar		Demonstration	SDI	Strategic Defense Initiative
BE	Brilliant Eyes	FLAGE	Flexible Lightweight Agile Guided Experiment	LEAP	Lightweight Exoatmospheric Projectile	SIE	SATKA Integrated Experiment
BM/C ³	Battle Management/Command, Control, and Communications	GB1	Ground-Based Interceptor	MEADS	Medium Extended Air Defense System	SM	Standard Missile
		GBR	Ground-Based Radar	MILSATCOM	Military Satellite Comms System	SMTS	Space and Missile Tracking System
BP	Brilliant Pebbles	GEM	Guidance Enhanced Missile	NAD	Navy Area Defense	SSTS	Space-based Surveillance and Tracking System
BSTS	Boost Surveillance and Tracking System	GPALS	Global Protection Against Limited Strikes	NMD	National Missile Defense		
CEC	Cooperative Engagement Capability	GSTS	Ground-based Surveillance and Tracking System	NTW	Navy Theater Wide	THAAD	Theater High Altitude Area Defense
CIS	Communications Interface Shelter	HEDI	High Endoatmospheric Defense Interceptor	PAC	Patriot Enhanced Capability	UEWR	Upgraded Early Warning Radar
DSP	Defense Support Program	HIT	Homing Interceptor Technology	TADIL-J	Tactical Digital Information Link "J"	WMD	Weapons of Mass Destruction
E21	Endo-Exoatmospheric Interceptor	HOE	Homing Overfly Experiment	TMD	Theater Missile Defense	XBR	X-Band Radar
EKV	Exoatmospheric Kill Vehicle	ICBM	InterContinental Ballistic Missile	SATKA	Surveillance, Acquisition, Tracking,		